IMPACT FATIGUE OF GRAPHITE

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Impact tensile fatigue experiments were carried out for two series of graphite specimen. The refined series showed higher strength compared with another one. The effect of specimen length on the fatigue strength could not be seen. Apparent fatigue limit was observed on each S-N diagram. The mechanism was considered by taking into account the initiation of small cracks. Zigzag crack propagation due to linking of a main crack with small cracks was observed. Impact fatigue strength was reduced at elevated temperature.

INTRODUCTION

Graphite is one of an indispensable material as a structural material for a nuclear reactor. However, dynamic loads must be carefully prevented because it is brittle. Nevertheless, it is expected that graphite blocks piled up in a reactor will be subjected to shocks and vibrations under a strong earthquake. Then, the study on impact fatigue strength of graphite is an important problem to secure the safe use of nuclear reactor in a country with frequent earthquakes. By the way, stress waves produced by an impact force construct very complicated dynamic stress state in a finite element[1-4]. It will be more complicated in a porous material such as graphite. Thus, the impact fatigue behavior of graphite has not been studied yet completely. Therefore, this study intend to make clear the characteristic properties.

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TABLE 1 - Mechanical Properties of Specimens

Property / Series	PGX	IG11
Tensile Strength (MPa)	9.3	25.5
Young's modulus (MPa)	6.47	10.0
Apparent density	1.74	1.78
Grain size (μm)	780(max)	20(max)

SPECIMENS AND EXPERIMENTAL APPARATUS

Materials used are usual structural graphite PGX and refined graphite IG11. Their physical and mechanical properties are listed in Table 1.

The short and long specimens were prepared as shown in Fig.1(a), and called S and L specimen, respectively. Notched specimens were used to observe crack growth behavior. Impact tension was pulsated 50 times per minute on each specimen by using a testing machine shown in Fig.1(b). For high temperature tests, an electric furnace was mounted on it. Impact stress was evaluated by multiplication of Young's modulus to the maximum of a strain pulse measured by a strain gauge pasted on the stress bar with consulting a calibration curve, which gives the relation between the stresses in a specimen and in the stress bar.

EXPERIMENTAL RESULTS AND DISCUSSIONS

S-N diagram

Experimental results were shown in Figs.2(a) and (b). The abscissa shows the number of cycle to fracture and the ordinate shows the stress pulsated. First of all, an apparent fatigue limit can be seen on each curve. Secondary, the impact fatigue limits of IG11 are about 1.3 times higher than that of PGX for both specimen lengths. Thirdly, fatigue strength of L specimen is slightly lower than that of S specimen for both series. This is considered to be a result of well known size effect, which says that the strength of large size specimen is less than that of the analogous small one. But, the difference between S and L specimens is very little in the case of IG11.

In order to consider these reasons, attenuation in strain pulse height for the propagating distance 90mm was investigated by using a circular rod of the diameter 20mm. Those results are expressed as follows.

$\varepsilon / \varepsilon_0 = \exp(-1.34L)$ for PGX

$\varepsilon / \varepsilon_0 = \exp(-0.745L)$ for IG11

Where, ε and ε_0 are strains at the origin of measuring and at the point distant L from it. These attenuations are remarkable compared with that of steel or PMMA, and it is due to the porosity of graphite. This property must reduces the stress pulse height which is constructed by the superposition of stress waves. That is, the mechanical size effect[1-4], which is contrary to the material size effect, is reduced especially in the case of porous material. Thus, it is considered that the material size effect was observed predominantly in the case of PGX.

Apparent fatigue limit

It is interesting to see that the apparent fatigue limit of each series is nearly comparable to respective characteristic strength, which can not be assigned definitely but is the strength for which the calibration curve between the stresses in the specimen and in the stress bar changed to non-linear from linear relation gradually above it. It is considered that the gradual change on each calibration curve was caused by the initiation and the subsequent growth of small cracks produced at porous defects when an applied stress exceeded it.

Crack Initiation and The Propagation Behavior

In order to see the influence of refinement on crack initiation, notched S specimens were used. The crack initiation life N_i is defined as the pulsated number till the sum of the lengths of crack originated at both notch roots grew up to 0.05mm. The results are shown in Figs.4(a)and(b). In these figures, impact fatigue strength was reduced about 25 per cent compared with smooth specimen for both series at $N_f = 10^4$, and the ratio of crack initiation life to the fracture life N_i/N_f of PGX was less than that of IG11.

It is also observed that a main crack propagated in zigzag way by linking with small cracks produced near the crack tip under a pulsating stress.

High temperature strength

According to Figs.5(a) and (b), PGX does not show clear fatigue limit at 779K although IG11 shows it as in the case of room temperature. The high temperature fatigue strengths are reduced to 66 and 80 per cent of strength at room temperature for PGX and IG11, respectively, at $N=10^3$. This result shows that the refinement was effective to improve the strength even at high temperature. However, the influence of oxidation were also included in these results.

CONCLUSION

The results are summarized as follows.

1. Apparent fatigue limit was observed on each S-N curve, and it was nearly comparable to the characteristic stress on the calibration curve between the stresses for a specimen and the stress bar.
2. Impact fatigue strength of long specimen was slightly less than that of short one in the case of PGX, but the difference was very small in the case of IG11. The reason was discussed based on the properties of stress wave propagation in a finite rod.
3. Notched specimen, of which stress concentration factor was about 7, reduced the strength about 25 per cent.
4. A main crack propagated in zigzag way by linking with small cracks produced near the crack tip.
5. Impact fatigue strengths were reduced for both series and apparent fatigue limit of PGX disappeared at 779K.
6. Refinement of graphite improved the strength in all cases in this study.

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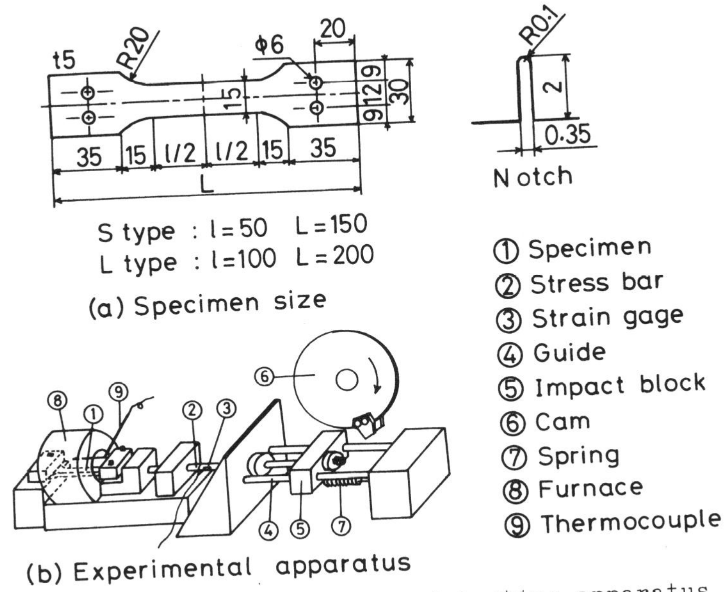

Figure 1 Dimension of specimen and testing apparatus

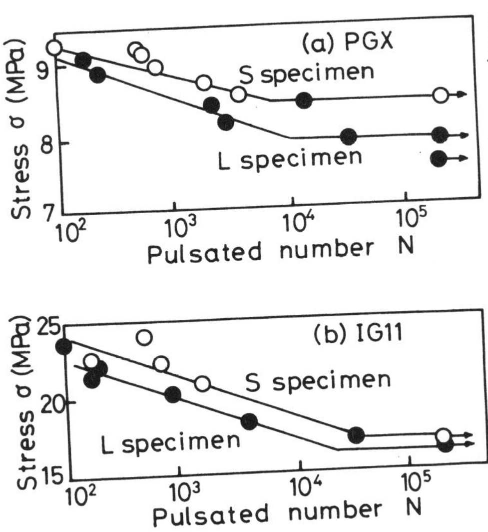

Figure 2 S-N curves of smooth specimen

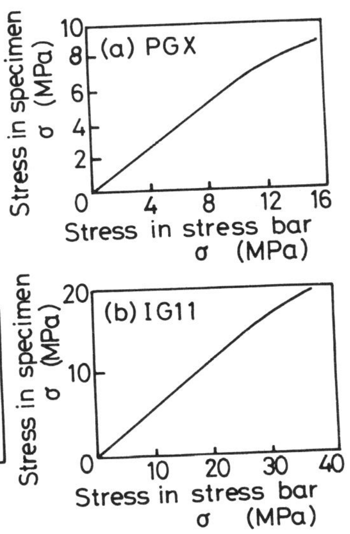

Figure 3 Calibration curves

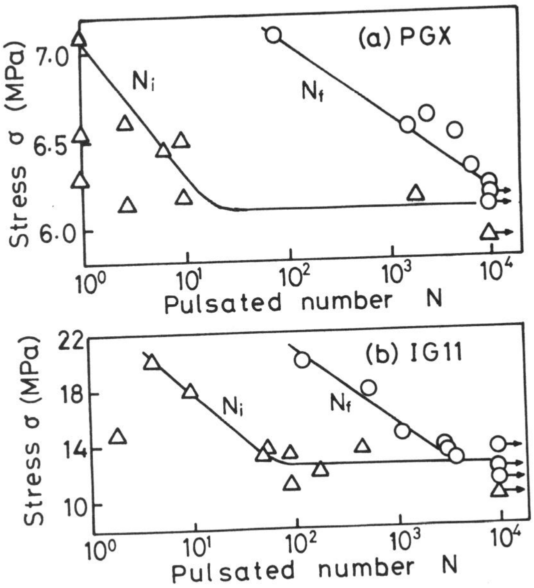

Figure 4 S-N curves of notched S specimen

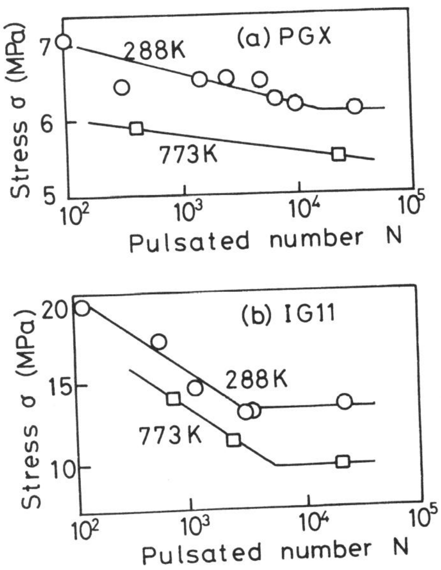

Figure 5 S-N curves of notched S specimen(288K and 773K)